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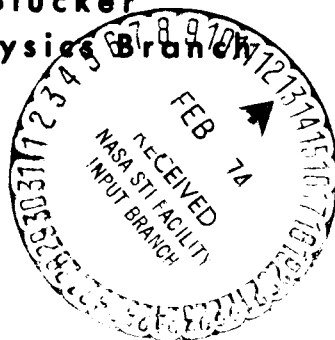
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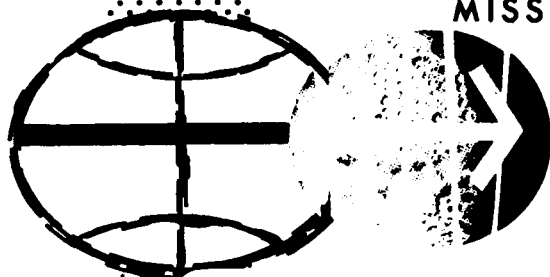
VERIFICATION OF THE RTCC LM  
OPTICS COMPUTATIONS FOR  
FIRST MANNED LM MISSION

By Troy J. Blucker  
Mathematical Physics Branch



MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER  
HOUSTON, TEXAS



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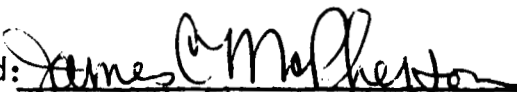
PROJECT APOLLO  
VERIFICATION OF THE RTCC LM OPTICS COMPUTATIONS  
FOR FIRST MANNED LM MISSION

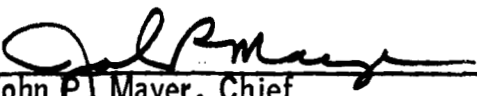
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Approved:   
James C. McPherson, Chief  
Mathematical Physics Branch

Approved:   
John P. Mayer, Chief  
Mission Planning and Analysis Division

# VERIFICATION OF THE RTCC LM OPTICS COMPUTATIONS

## FOR FIRST MANNED LM MISSION

By Troy J. Blucker

### SUMMARY

This note contains the formulation for verification of the Real-Time Computer Complex (RTCC) LM optics computations which are provided to determine if correct inertial measurement unit (IMU) stable-member alignment has been attained during the first manned LM mission. The calculations serve the following functions.

1. To determine the alignment optical telescope (AOT) shaft and trunnion angles of a given star in the field of view.
2. To determine the reticle coordinates of a given star in the crewman optical alignment sight (COAS) viewfield.

### INTRODUCTION

After each alignment of the LM IMU stable member, the RTCC can determine if the new alignment is correct based on onboard star sightings. A program written by the author and George Austin of Analytic Mechanics Associates is now available to verify these computations. This is accomplished by an independent computation of star sighting angles and viewfield coordinates of stars with respect to instrument reticle patterns for the two optical instruments, the AOT and the COAS, currently planned for the LM. The program is capable of calculating the following:

1. The shaft and trunnion angles of a given star in the AOT field of view.
2. The reticle pattern coordinates of a given star in the COAS field of view.

Additional pertinent applications of this program are to verify star identification during navigation sightings, to aid the astronaut in sighting stars in the field of view, and to provide an important emergency backup mode for manual spacecraft alignment and attitude control.

## SYMBOLS

IMU	inertial measurement unit
$\hat{R}$	unit vector in direction of arbitrary vector R
$\hat{S}_*$	unit vector in direction of star
$X_{NB}, Y_{NB}, Z_{NB}$	axes of spacecraft navigation base coordinate system
$X_B, Y_B, Z_B$	axes of spacecraft body coordinate system
$\hat{L}$	unit vector in direction of optical instrument line of sight
COAS	crewman optical alignment sight
AOT	alignment optical telescope
EL	elevation of star in COAS viewfield
SXP	star X position in COAS viewfield
Sh	shaft angle of AOT
Tr	trunnion angle of AOT
ECI	earth centered inertial

## ALIGNMENT OPTICAL TELESCOPE

The AOT is a unity power telescope with a  $60^\circ$  field of view and has three sighting positions as shown in figure 1; the  $0^\circ$  position is in the X-Z body plane and  $45^\circ$  above the Z axis, the other positions are  $60^\circ$  to the right ( $+60$ ) or left ( $-60$ ) of the  $0^\circ$  position. The function of the AOT is to supplement the rendezvous radar by measuring azimuth and elevation angles to stars for alignment of the LM IMU stable member (ref. 1). The AOT shaft and trunnion angles are illustrated in the reticle pattern in figure 2 and may be thought of as the rotation required about the instrument line of sight to put the heavy upper reticle line on the star and the angle from the center of the viewfield to the star (ref. 2), respectively.

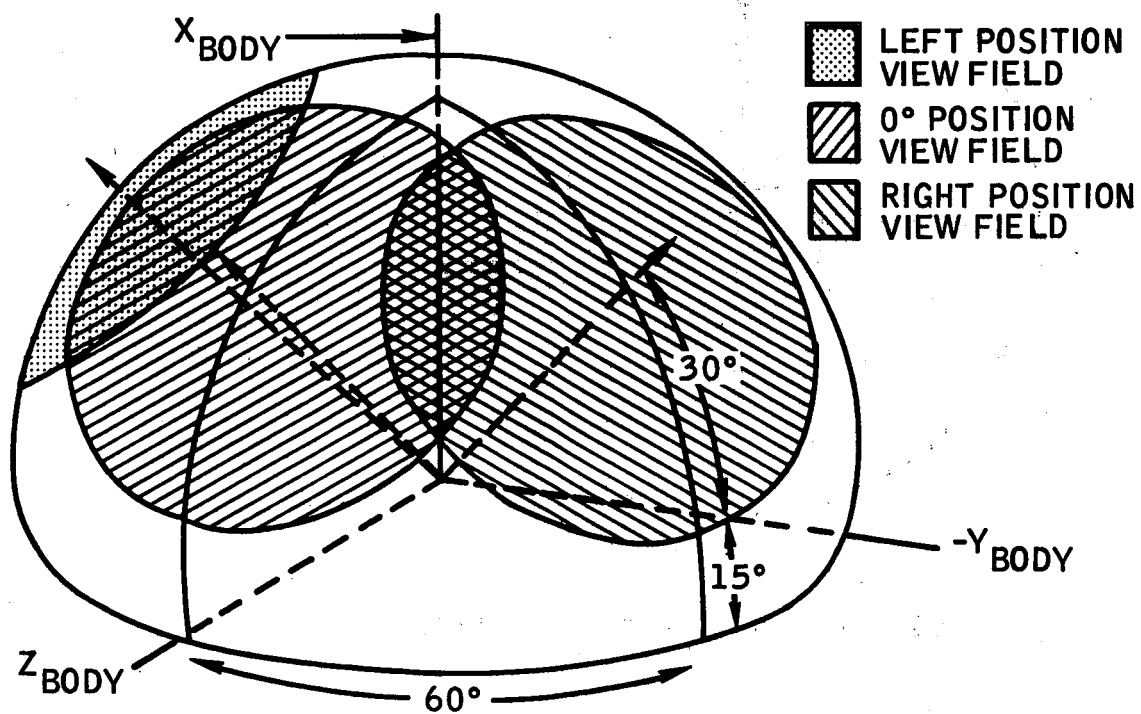


Figure 1.- AOT view-field coverage.

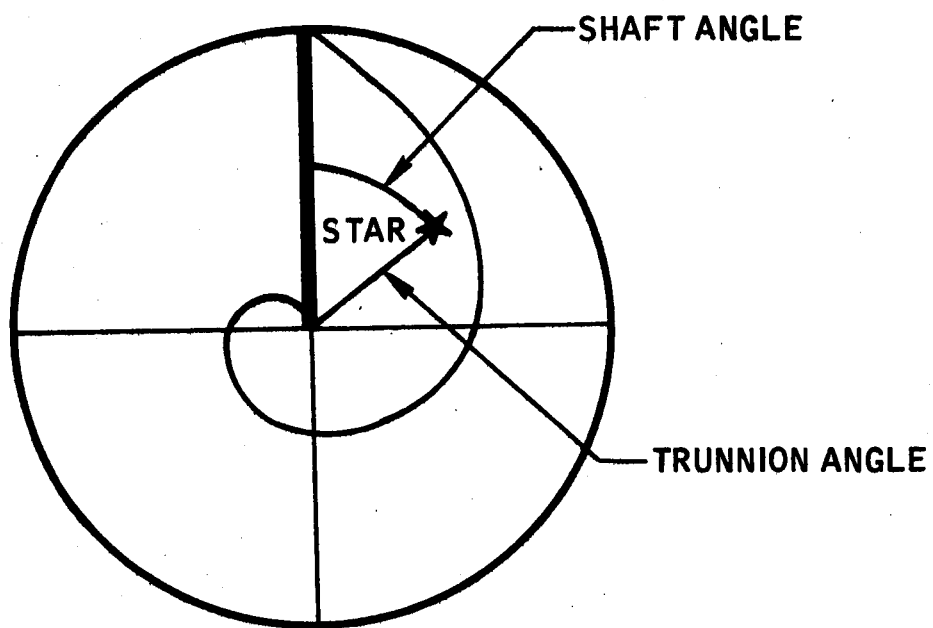


Figure 2.- AOT shaft and trunnion angles.

### Location of Star in AOT Viewfield

The AOT shaft and trunnion angles which define the position of a star in the viewfield are calculated assuming the following are known:

1. The celestial orientation of the star.
2. The orientation of the spacecraft IMU stable member in inertial space.
3. The IMU gimbal angles<sup>a</sup>.

The calculations are made in the spacecraft body coordinates which are the same as navigation base coordinates for the LM.

If the AOT field of view is extended to the celestial sphere, the shaft and trunnion angles of a star are defined as illustrated in figure 3 when the instrument is in the 0° forward position.

The calculation of each star appearing in the AOT field of view is as follows:

Assume:	$\hat{L}$	AOT line-of-sight unit vector
	$\hat{S}$	star line-of-sight unit vector
	$\theta$	angle between $\hat{S}$ and $\hat{X}_{BODY}$
	Tr	AOT trunnion angle
	Sh	AOT shaft angle

The trunnion angle is simply

$$Tr = \cos^{-1}(\hat{L} \cdot \hat{S})$$

From spherical trigonometry,

$$\cos \theta = \cos 45^\circ \cos Tr + \sin 45^\circ \sin Tr \cos Sh$$

so that the shaft angle is

$$Sh = \cos^{-1} \left[ \frac{\cos \theta - \cos 45^\circ \cos Tr}{\sin 45^\circ \sin Tr} \right]$$

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<sup>a</sup>The IMU gimbal angles define the attitude of the LM spacecraft with respect to the IMU stable member orientation which remains fixed in inertial space.

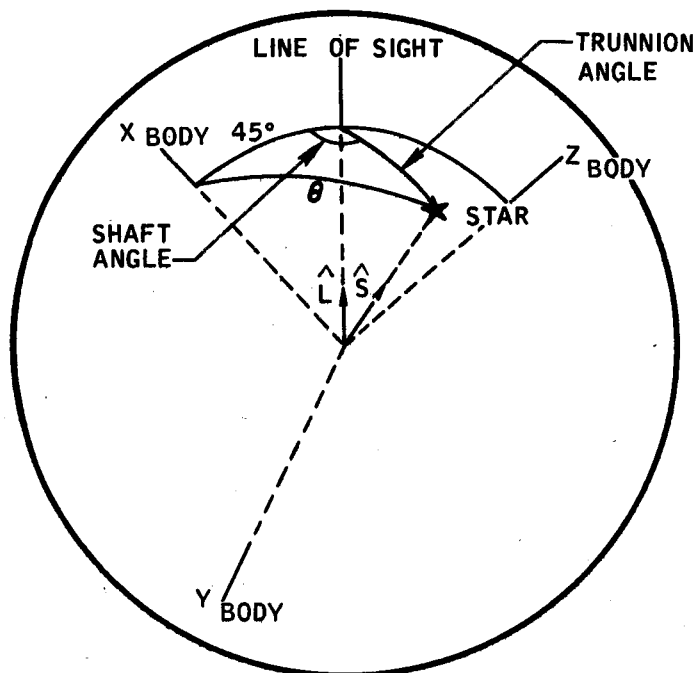


Figure 3.- AOT angles on celestial sphere in 0° position.

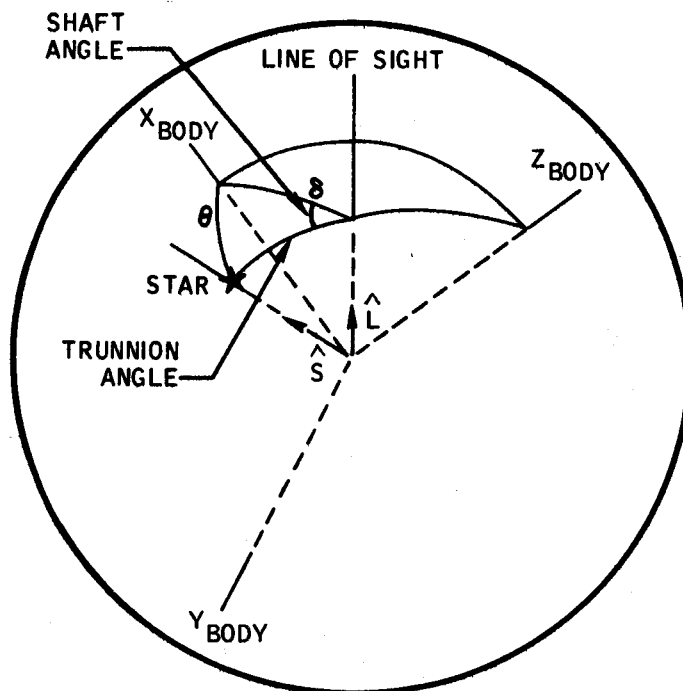


Figure 4.- AOT angles on celestial sphere in + 60° position.



where

$$\theta = \cos^{-1}(\hat{X} \cdot \hat{S})$$

For the right and left positions of the AOT, the formulation is slightly changed as the instrument line of sight ( $\hat{L}$ ) is no longer in the body X-Z plane. For the right (+60°) position, the star shaft and trunnion angles are defined in figure 4 as projected on the celestial sphere.

The calculation of each star appearing in the AOT viewfield when in the right position is as follows:

The trunnion angle is again simply

$$Tr = \cos^{-1}(\hat{L} \cdot \hat{S})$$

From spherical trigonometry,

$$\cos \theta = \cos \delta \cos Tr + \sin \delta \sin Tr \cos Sh$$

where  $\delta$  is the angle between  $\hat{L}$  and  $\hat{X}_{BODY}$ .

Then the shaft angle is

$$SH = \cos^{-1} \left[ \frac{\cos \theta - \cos \delta \cos Tr}{\sin \delta \sin Tr} \right]$$

where

$$\theta = \cos^{-1}(\hat{S} \cdot \hat{X}_{BODY})$$

and

$$\delta = \cos^{-1}(\hat{L} \cdot \hat{X}_{BODY})$$

The formulation of the star shaft and trunnion angles with the AOT in the left (-60°) position is identical to that of the right (+60°) position. It would be necessary, however, to determine in which of the viewing positions the star would be visible in addition to the necessary shaft and trunnion angles. This can be done by computing the unit vector of the line of sight for each viewing position ( $\hat{L}$ ). A check is then made on the angle between  $\hat{L}$  for each position and the unit vector along the line of sight of the star ( $\hat{S}$ ). The star is visible to the AOT in the correct position when

$$\cos^{-1}(\hat{L} \cdot \hat{S}) < 30^\circ$$

for each  $\hat{L}$ .

The trunnion angle is always positive and not greater than  $30^\circ$ , that is,

$$0^\circ \leq Tr \leq 30^\circ.$$

The shaft angle is positive and not greater than  $360^\circ$ , that is,

$$0^\circ \leq Sh \leq 360^\circ.$$

Since the cosine function is used to compute the shaft angle, the computed angle will be

$$-180^\circ \leq Tr \leq 180^\circ,$$

but this may be corrected by

$$Sh = 360^\circ - Sh$$

when Sh has been computed to be negative.

#### COAS Reticle Pattern Coordinates of a Star

The COAS is a  $10^\circ$  field-of-view instrument with one degree of freedom termed EL (elevation) in the LM optics support table. It can be mounted on the commander's side in either the overhead window (X-axis mount) or the forward window (Z-axis mount).

When mounted in the overhead window, the instrument line of sight can be rotated about an axis parallel to the LM Y axis from a zero position parallel to the LM +X axis,  $35^\circ$  toward the LM +Z axis, or  $5^\circ$  toward the LM -Z axis. A positive EL is toward the -Z axis and a negative EL is toward the +Z axis (fig. 5).

The EL rotation will place a target on a reticle cross line which is parallel to the axis of rotation of the COAS. The position on this reticle line is referred to in the LM optics support table display as SXP (star X position). A reticle line position toward the LM +Y axis will be positive and toward the -Y axis will be negative. SXP ranges between  $\pm 5^\circ$ .

When COAS is mounted in the forward window, the instrument line of sight can be rotated about an axis parallel to the LM X axis  $40^\circ$  to either side of a zero position (fig. 6). The zero position is  $30^\circ$  from the +Z axis toward the -Y axis. EL is positive toward the LM -Y axis and negative toward the +Y axis. A line of sight parallel to the LM +Z axis has a  $-30^\circ$  EL. A positive SXP is toward the LM +X axis and a negative SXP is toward the LM -X axis (ref. 3).

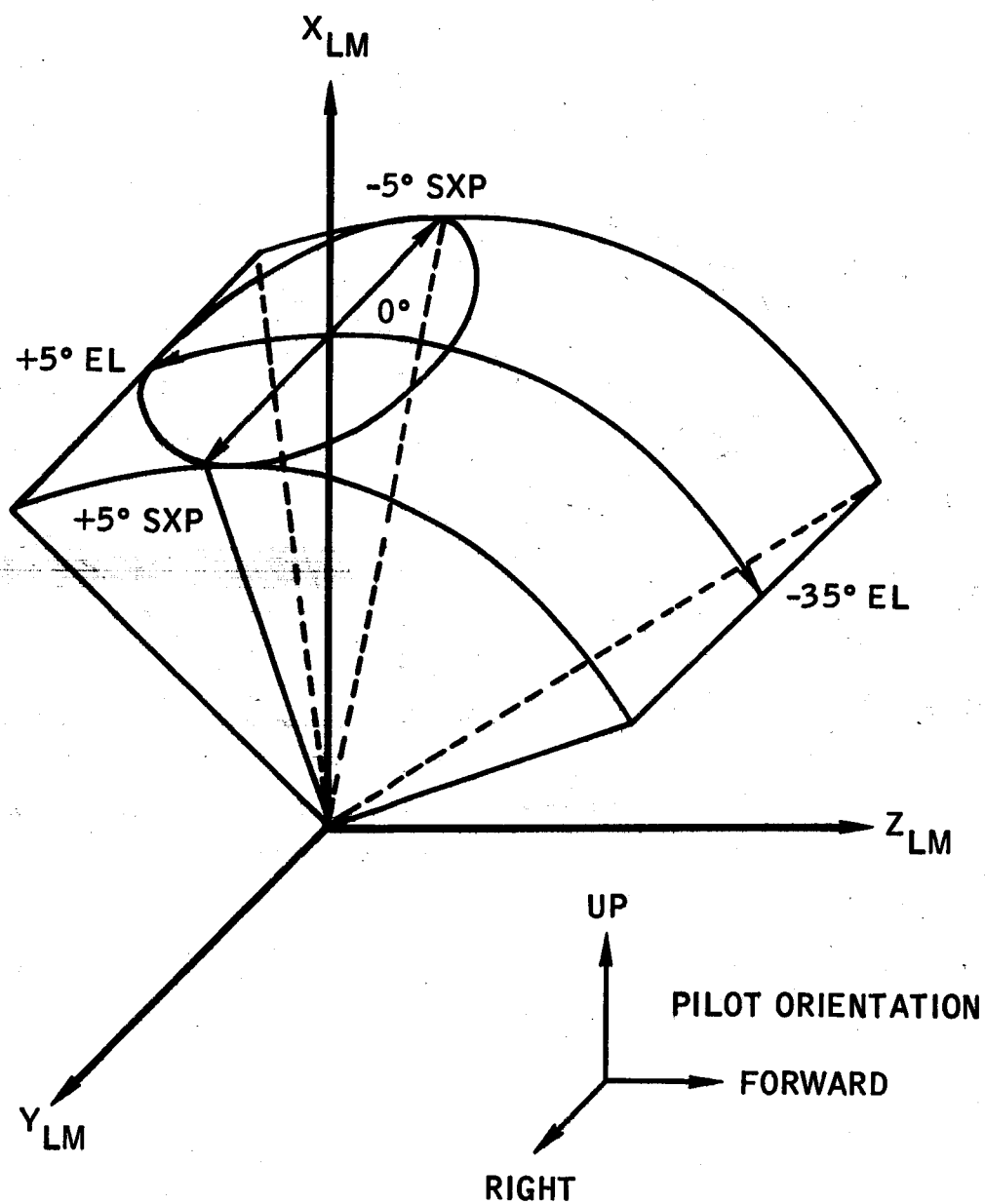


Figure 5.- COAS forward window mount ( $\hat{X}$ -axis) (target at infinite distance).

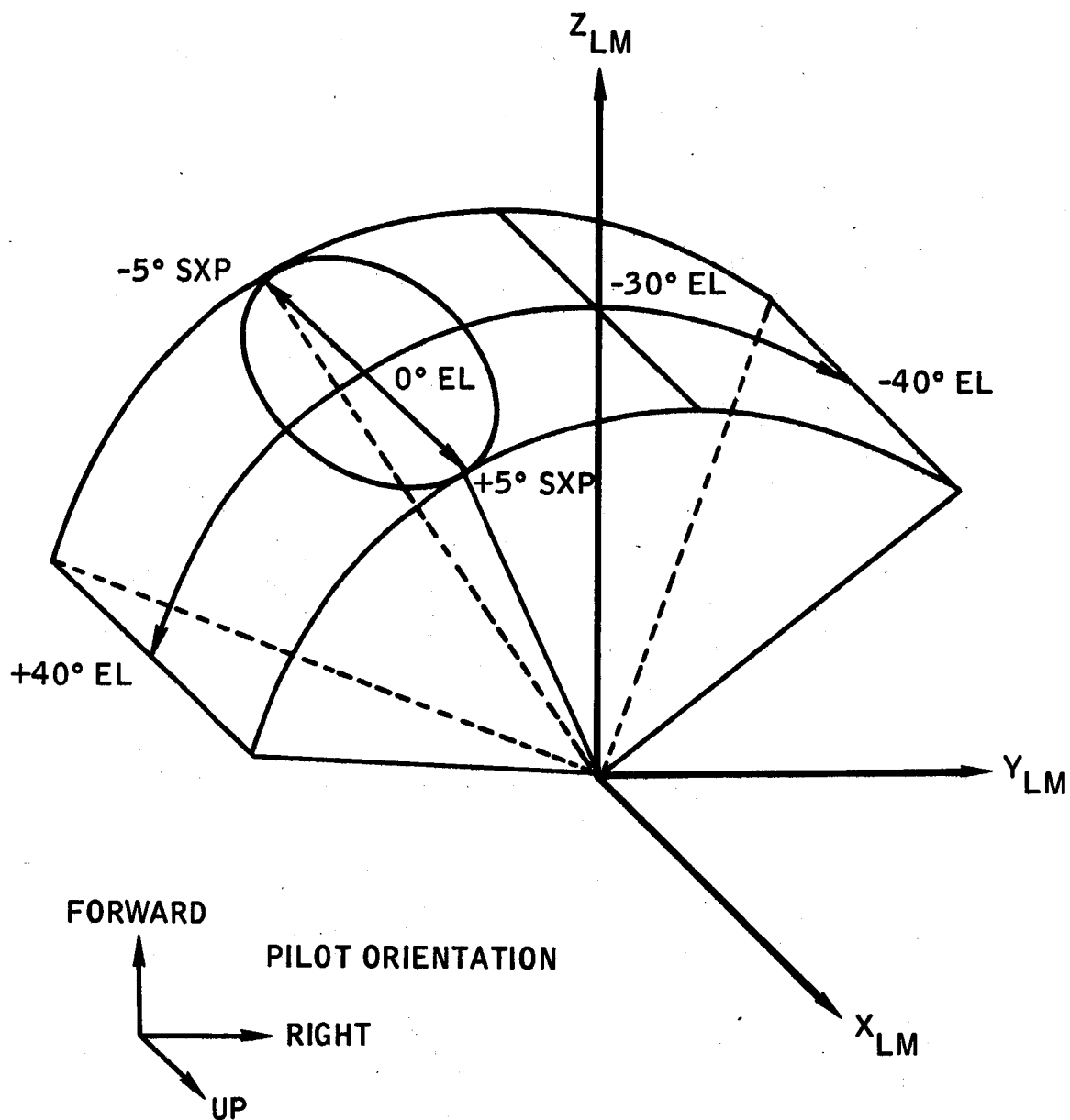


Figure 6.- COAS forward window mount (Z-axis) (target at infinite distance).

The coordinates of a star with respect to the COAS reticle pattern are calculated assuming the following are known.

1. The celestial coordinates of the star that is sighted with the COAS.
2. The orientation of the spacecraft IMU stable member in inertial space.
3. The IMU gimbal angles.
4. The mount or viewing position of the COAS.

If the COAS field of view is extended to the celestial sphere, the star appears in the reticle pattern as shown in figure 7, and the view-field coordinates are determined as illustrated in the enlarged part of the viewfield (fig. 8).

Assume the COAS is positioned on the X axis. Let  $\epsilon$  be the arc between the star and the center of the viewfield on the celestial sphere; then

$$\epsilon = \cos^{-1}(\hat{S}_* \cdot \hat{L})$$

where  $\hat{S}_*$  and  $\hat{L}$  are the unit vectors to the star and the COAS line of sight, respectively.

Let  $\gamma$  be the arc between the star and the Z axis on the celestial sphere; then

$$\gamma = \cos^{-1}(\hat{S}_* \cdot \hat{Z})$$

Let  $\alpha$  and  $\theta$  be the angles as illustrated in figure 8.

$$\alpha = \tan^{-1}\left(\frac{S_2}{S_1}\right)$$

where  $S_1$  and  $S_2$  are the X and Y components of  $\hat{S}_*$  in navigation base coordinates. Then from spherical trigonometry

$$\theta = \sin^{-1}\left[\frac{\sin \gamma \sin \alpha}{\sin \epsilon}\right]$$

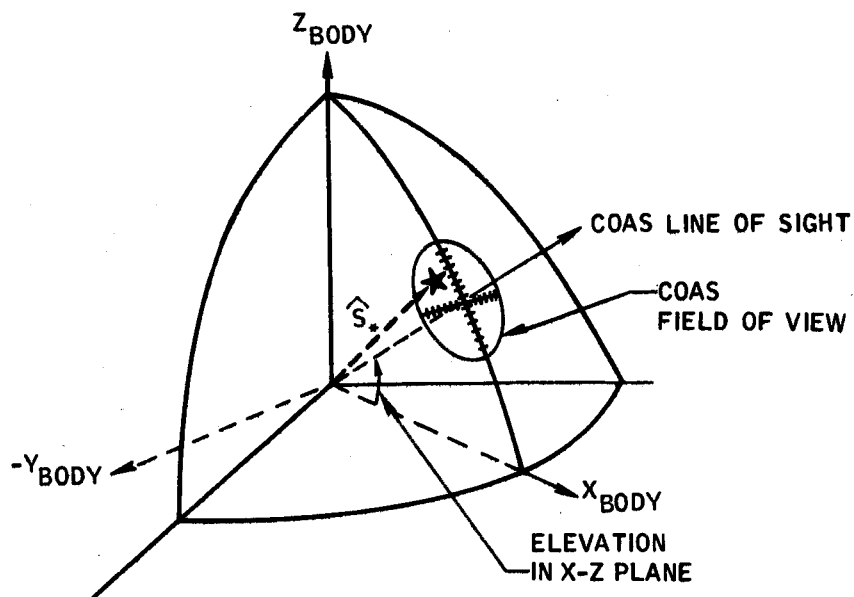


Figure 7.- COAS field of view on celestial sphere.

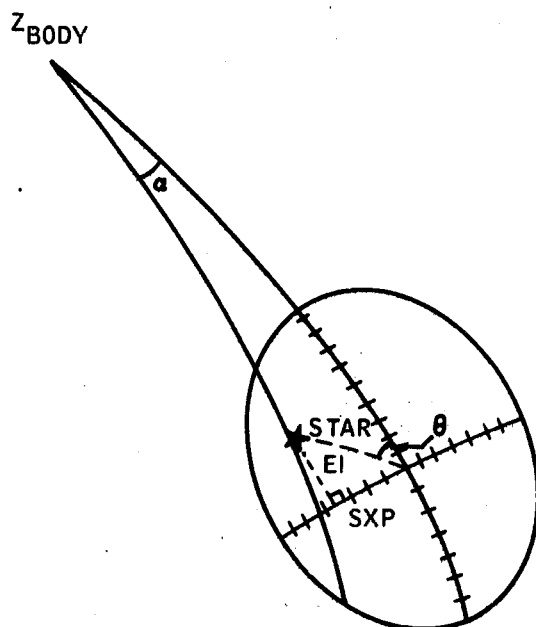


Figure 8.- Enlarged COAS reticle pattern.

Let

$$\delta = 90^\circ - \theta \text{ if } \theta < 90^\circ$$

$$\delta = \theta - 90^\circ \text{ if } \theta > 90^\circ$$

Finally, from spherical trigonometry

$$EL = \sin^{-1}[\sin \delta \sin \epsilon]$$

$$SXP = \cos^{-1} \left[ \frac{\cos \epsilon}{\cos EL} \right]$$

If the COAS is positioned on the Z axis the computations for SXP and EL differ only slightly from those for the X-axis position. For this position the unit vector along the Z axis ( $\hat{Z}$ ) is substituted for the unit vector along the X axis ( $\hat{X}$ ) in the computation, and the unit vector along the X axis ( $\hat{X}$ ) is substituted for the unit vector along the Z axis ( $\hat{Z}$ ). Then changes would be:

$$\epsilon = \cos^{-1}(\hat{S}_* \cdot \hat{Z})$$

and

$$\gamma = \cos^{-1}(\hat{S}_* \cdot \hat{X})$$

and

$$\alpha = \tan^{-1} \left[ \frac{S_1}{(S_2^2 + S_3^2)^{\frac{1}{2}}} \right]$$

where  $S_1, S_2, S_3$  are the components of  $\hat{S}_*$  in navigation base coordinates.

Also, since the null Z position of the COAS is offset as illustrated in figure 6, the computed EL angle (which was computed as if the null position was along the Z axis) is altered by subtracting  $30^\circ$ .

#### PROGRAM

Table I defines the input information and sequence that would be necessary for this program. It is possible to assemble as many of these data stacks as desired if the order is maintained and an ENDCAS card following each case.

Table II illustrates sample listings of the output for the program. The headings in the output listing are defined as follows:

Alpha, Beta, Gamma:	Inner, middle and outer IMU gimbal angles
Gimbal Angle Matrix:	Rotation matrix from IMU stable member to LM body coordinates.
Refsmmat:	Rotation matrix from earth-centered inertial (ECI) to IMU stable member coordinates.
Star Name:	LGC star catalogue name
Star Number:	LGC star catalogue number
R.A.:	LGC star catalogue ECI right ascension
Declination:	LGC star catalogue ECI declination
SPX:	Star X position in COAS viewfield
EL:	Star elevation in COAS viewfield
Zero, +60, -60 position:	Forward, right, and left viewing position of AOT
Shaft, Trunnion Angles:	AOT shaft and trunnion angles

The program has been coded in FORTRAN IV for use on the IBM 7094. A listing of the program along with sample input data is given in table III.



TABLE I.- PROGRAM INPUT

Card number	Column number	Integer (I), floating (F), or alphanumeric (A)	Description
1	1 - 15	F	IMU inner gimbal angle (pitch)
	16 - 30	F	IMU middle gimbal angle (roll)
	31 - 45	F	IMU outer gimbal angle (yaw)
2, 3, 4	1 - 15	F	3 x 3 rotation matrix from
	16 - 30	F	Earth-centered inertial to LM stable member
	31 - 45	F	Coordinates (one row per card)
5	1 - 12	A	Star name
	13 - 17	I	Star catalogue number
	18 - 22	F	Right ascension of star (hours)
	23 - 27	F	Right ascension of star (minutes)
	28 - 37	F	Right ascension of star (seconds)
	38 - 42	F	Declination of star (degrees)
	43 - 47	F	Declination of star (minutes)
	48 - 57	F	Declination of star (seconds)
6	1 - 6	A	ENDCAS - end case card to separate cases of data

TABLE II.- PROGRAM OUTPUT

## GIMBAL ANGLES ARE

ALPHA =, 0.90000000D 02 BETA =, 0.90000000D 02 GAMMA = 0.33000000D 03

## GIMBAL ANGLE MATRIX

0.30814879D-30	0.10000000D 01	-0.55511151D-15
-0.50000000D 00	0.48074067D-15	0.86602540D 00
0.86602540D 00	0.27755576D-15	0.50000000D 00

## REFSMAT

0.10000000D 01	0.	0.
0.	0.10000000D 01	0.
0.	0.	0.10000000D 01

STAR NAME	NUMBER,	R.A.	DECLINATION
TEST222	222	0.44375000D 01	-0.90066667D 01

USE +Z FOR COAS AXIS

SPX = 0.27726985D 01 EL = 0.91573142D 01

STAR IS NOT VISIBLE TO AOT

STAR NAME	NUMBER,	R.A.	DECLINATION
TEST319	319	0.35940417D 03	0.66805556D 01

USE +Z FOR COAS AXIS

SPX = -0.23423728D 00 EL = -0.66749349D 01

STAR IS NOT VISIBLE TO AOT

## TABLE II.- PROGRAM OUTPUT - Concluded.

## GIMBAL ANGLES ARE

ALPHA =, 0.30000000D 02 BETA =, 0.50000000D 02 GAMMA = 0.40000000D 02

## GIMBAL ANGLE MATRIX

0.55667040D 00	0.76604444D 00	-0.32139380D 00
-0.18681076D 00	0.49240388D 00	0.85008244D 00
0.80945649D 00	-0.41317591D 00	0.41721201D 00

## REFSMAT

-0.81543940D 00	-0.57131830D 00	0.93026000D-01
-0.55869010D 00	0.81885640D 00	0.13167980D 00
-0.15140600D 00	0.55404300D-01	-0.98691760D 00

STAR NAME	NUMBER,	R.A.	DECLINATION
TESTSTAR 1	1900	0.17684583D 03	0.14756389D 02

## USE +X FOR COAS AXIS

SPX = 0.43115537D 01 EL = -0.19542015D 02

## USE ZFRC INDENT

SHAFT ANGLE = 0.94001935D 01 TRUNION ANGLE = 0.30849879D 03

STAR NAME	NUMBER,	R.A.	DECLINATION
TESTSTAR 2	2000	0.18352500D 03	-0.17358889D 02

## NOT VISIBLE TO COAS

## USE ZFRC INDENT

SHAFT ANGLE = 0.89526206D 02 TRUNION ANGLE = 0.31557877D 03

TABLE III.- SAMPLE PROGRAM LISTING

```

DOUBLE PRECISION RMAT(3,3),GA(3,3),SI(3),SN(3),TEMP(3),T1(3,3)
1,PI,CRAD,ALPHA,BET,GAMMA,HRS,AMIN,SEC,DEG,DMIN,DSEC,RAD,DECD,RA,
2 DEC,EPS,GAM,ALP,ARG1,SCV,ARG2,R,ARG3,SPX,EL,HYP,XL,YL,ZL,COTR,RO,
3 YZANG,SH,TR,T2(3,3),BETA
DATA ENDCAS/6HENDCAS/
INTEGER ENDCAS
C   RA      = RIGHT ASCENSION
C   DEC     = DECLINATION
C   INPUT REFSMAT TO CONVERT TO NAVBASE
C   INPUT GIMBAL ANGLE MATRIX
C   RMAT     = REFSMAT MATRIX
C   GA      = GIMBAL ANGLE MATRIX
C   SI      = STAR POSITION VECTOR - ECI
C   SN      = STAR POSITION VECTOR - NAVBASE
PI      =3.14159265358979300
CRAD    =PI/180.00
C   INPUT GIMBAL ANGLES IN DEGREES
1 CONTINUE
READ(5,15) ALPHA,BETA,GAMMA
15 FORMAT(3D15.6)
C   SET UP GIMBAL ANGLE MATRIX
GA(1,1)=DCOS(ALPHA*CRAD)
GA(1,2)=0.0
GA(1,3)=DSIN(ALPHA*CRAD)
GA(2,1)=0.0
GA(2,2)=1.0
GA(2,3)=0.0
GA(3,1)=-GA(1,3)
GA(3,2)=0.0
GA(3,3)=GA(1,1)
T1(1,1)=DCOS(BETA*CRAD)
T1(1,2)=-DSIN(BETA*CRAD)
T1(1,3)=0.0
T1(2,1)=-T1(1,2)
T1(2,2)=T1(1,1)
T1(2,3)=0.0
T1(3,1)=0.0
T1(3,2)=0.0
T1(3,3)=1.0
DO 5 I=1,3
DO 5 J=1,3
T2(1,J)=0.0
DO 5 K=1,3
5 T2(1,J)=GA(1,K)*T1(K,J)+T2(1,J)
T1(1,1)=1.0
T1(1,2)=0.0
T1(1,3)=0.0
T1(2,1)=0.0
T1(2,2)=DCOS(GAMMA*CRAD)
T1(2,3)=-DSIN(GAMMA*CRAD)
T1(3,1)=0.0
T1(3,2)=-T1(2,3)
T1(3,3)=T1(2,2)
DO 8 I=1,3
DO 8 J=1,3
GA(J,I)=0.0
DO 8 K=1,3

```

TABLE III.- SAMPLE PROGRAM LISTING - Continued

```

      8  GA(J,I)=T2(I,K)*T1(K,J)+GA(J,I)
      READ(5,15)((RMAT(I,J),J=1,3),I=1,3)
      WRITE(6,9)ALPHA,BETA,GAMMA
      9  FORMAT(18H GIMBAL ANGLES ARE/9H ALPHA =,D15.8,8H BETA =,D15.8,
      1  8H GAMMA =,D15.8///)
      WRITE(6,25)((GA(I,J),J=1,3),I=1,3)
      25  FORMAT(20H GIMBAL ANGLE MATRIX/3(3D20.8/)/)
      WRITE(6,35)((RMAT(I,J),J=1,3),I=1,3)
      35  FORMAT( 9H REFSMAT /3(3D20.8/)/)
      40  READ(5,27)NAME1,NAME2,NO,HRS,AMIN,SEC,DEG,DMIN,DSEC
      27  FORMAT(2A6,I5,D5.2,D5.2,D10.5,D5.2,D5.2,D10.5)
      IF(NAME1.EQ.  ENDCAS) GO TO 1
      RAD  =15.000*(HRS+AMIN/60.000+SEC/3600.000)
      DECD =DEG+DMIN/60.000+DSEC/3600.000
      WRITE(6,29)NAME1,NAME2,NO,RAD,DECD
      29  FORMAT(//
      1  10H STAR NAME,5X,8H NUMBER,3X,5H R.A.,10X,12H DECLINATION/
      1  1H ,2A6,3X,I5,3XD15.8,3X,D15.8///)
      RA  =RAD*CRAD
      DEC =DECD*CRAD
      C    COMPUTE INERTIAL UNIT VECTOR
      SI(1) =DCOS(DEC)*DCOS(RA)
      SI(2) =DCOS(DEC)*DSIN(RA)
      SI(3) =DSIN(DEC)
      C    ROTATE BY REFSMAT
      DO 60 I=1,3
      TEMP(I)=0.0
      DO 60 J=1,3
      60  TEMP(I)=TEMP(I)+RMAT(I,J)* SI(J)
      C    ROTATE BY GIMBAL ANGLES
      DO 70 I=1,3
      SN(I) =0.0
      DO 70 J=1,3
      70  SN(I) =SN(I)+ GA(I,J)*TEMP(J)
      C    TEST FOR COAS VISIBILITY
      IF(DABS(SN(2))-DCOS(5.000*CRAD))80,109,109
      C    STAR WITHIN FIVE DEGREES OF THE X-Z PLANE
      80 IF(SN(3))84,82,82
      82 IF( ARCOS(SN(1))-35.000*CRAD)100,100,109
      84 IF( ARCOS(SN(1))-5.000*CRAD)100,100,109
      C    USE X-AXIS
      100 EPS  = ARCOS(SN(1))
      GAM  = ARCOS(SN(3))
      ALP  =DATAN(SN(2)/SN(1))
      ARG1 =DSIN(GAM)*DSIN(ALP)/DSIN(EPS)
      SCV  =0.500*PI-DABS( ARSIN(ARG1))
      ARG2 =DSIN(SCV)*DSIN(EPS)
      R    =SN(3)*DABS( ARSIN(ARG2)/SN(3))
      ARG3 =DCOS(EPS)/DCOS(R)
      SPX  =SN(2)*DABS( ARCOS(ARG3)/SN(2))/CRAD
      IF(SN(2))101,102,102
      101 SPX  =-DABS(SPX)
      GO TO 103
      102 SPX  = DABS(SPX)
      103 EL  = R/CRAD
      IF(SN(3))104,106,106
      104 EL  = DABS(EL)
      GO TO 107
      106 EL  =-DABS(EL)
      107 WRITE(6,105)

```

TABLE III.- SAMPLE PROGRAM LISTING - Continued

```

105  FORMAT(21H USE +X FOR COAS AXIS///)
      GO TO 140
109  IF(DABS(SN(1))-DCOS(85.00*CRAD))115,115,150
C    STAR WITHIN 5 DEGREES OF Y-Z PLANE
115  IF(SN(2))125,118,118
118  IF( ARCOS(SN(3))-10.00*CRAD)130,150,150
125  IF( ARCOS(SN(3))-70.00*CRAD)130,150,150
C    USE Z-AXIS
130  EPS  = ARCOS(SN(3))
      GAM = ARCOS(SN(1))
      HYP  =DSQRT(SN(1)*SN(1)+SN(2)*SN(2))
      ALP  =DATAN(HYP/SN(3))
      SCV  =0.500*PI-DABS( ARSIN(DSIN(GAM)*DSIN(ALP)/DSIN(EPS)))
      R    =SN(1)*DABS( ARSIN(DSIN(SCV)*DSIN(EPS))/SN(1))
      IF(SN(1))121,122,122
121  SPX  =-DABS(R)
      GO TO 124
122  SPX  = DABS(R)
124  EL   =SN(2)*DABS( ARCOS(DCOS(EPS)/DCOS(SPX))/SN(2))/CRAD
      IF(SN(2))126,127,127
126  EL   =DABS(EL)
      GO TO 128
127  EL   =-DABS(EL)
128  EL   =EL-30.00
      SPX  = SPX/CRAD
      WRITE(6,135)
135  FORMAT(21H USE +Z FOR COAS AXIS///)
140  WRITE(6,145)SPX,EL
145  FORMAT(6H SPX =,D16.8,5H EL =,D16.8///)
      GO TO 230
150  WRITE(6,155)
155  FORMAT(20H NOT VISIBLE TO COAS///)
C    BEGIN AOT
230  KEY  = 0
      XL  =DSQRT(2.00)*0.500
      YL  = 0.0
      ZL  =DSQRT(2.00)*0.500
      COTR = XL*SN(1)+ZL*SN(3)
      RO  = ARCOS(COTR)
      IF (RO-30.00*CRAD)250,240,240
240  YL  =DSQRT(6.00)*0.2500
      ZL  =DSQRT(2.00)*0.2500
      YZANG =DATAN(SN(2)/SN(3))
      COTR = XL*SN(1)+YL*SN(2)+ZL*SN(3)
      RO  = ARCOS(COTR)
      IF (RO-30.00*CRAD)260,245,245
245  YL  = -YL
      COTR = XL*SN(1)+YL*SN(2)+ZL*SN(3)
      RO  = ARCOS(COTR)
      IF (RO-30.00*CRAD)270,300,300
C    USE ZERO INDENT FOR AOT
250  WRITE(6,255)
255  FORMAT(16H USE ZERO INDENT)
      SH  =0.0
      IF(SN(2))257,290,290
257  KEY  = 1
      GO TO 290
C    USE +60 INDENT FOR AOT
260  WRITE(6,265)
265  FORMAT(15H USE +60 INDENT///)

```

TABLE III.- SAMPLE PROGRAM LISTING - Concluded

```

SH      = 60.0
IF (YZANG-PI/3.0D0)267,290,290
267 KEY  = 1
GO TO 290
C      USE -60 INDENT FOR AOT
270 WRITE(6,275)
275 FORMAT(15H USE -60 INDENT///)
SH      =-60.0
IF (PI/3.0D0-YZANG)277,290,290
277 KEY  = 1
290 SH    = ARCOS((SN(1)-COTR*XL)/(XL*DSIN(R0)))/CRAD+SH
TR      =R0/CRAD*12.0D0
IF(KEY)292,292,291
291 SH    =360.0D0-SH
292 WRITE(6,295)SH,TR
295 FORMAT(14H SHAFT ANGLE =,D16.8,16H TRUNION ANGLE =,D16.8)
GO TO 40
300 WRITE(6,305)
305 FORMAT(27H STAR IS NOT VISIBLE TO AOT)
GO TO 40
END

```

```

30.0      50.0      40.0
-.8154394  -.5713183  .0930260
-.5586901  .8188564  .1316798
-.1514060  .0554043  -.9869176
TESTSTAR 1 19 11. 47. 23.      14. 45. 23.
TESTSTAR 2 20 12. 14. 6.      -17. -21. -32.
ENDCAS

```

```

30.0      50.0      40.0
-.8226739  -.5640871  .0641107
-.5488742  .8185725  .1693405
-.1481376  .1041233  -.9834702
TESTSTAR 3 19 11. 47. 23.      14. 45. 23.
TESTSTAR 2 20 12. 14. 6.      -17. -21. -32.
ENDCAS

```

```

0.      360.0      0.0
.9451998  -.3075566  .1095721
-.2877396  -.9432868  -.1655770
.1542823  .1249751  -.9800908
TESTSTAR 5 2 0. 41. 56.      -18. -10. -3.
TESTSTAR 6 4 1. 36. 29.      -57. -24. -15.
ENDCAS

```

```

0.0      360.0      0.0
.9999999  .0      .0
.0      .9999999  .0
.0      .0      .9999999
TESTSTAR 7 1 0. 6. 41.      28. 54. 30.
TESTSTAR 8 3 0. 54. 42.      60. 32. 19.
ENDCAS

```

```

10.0      30.0      20.0
.9999999  .0      .0
.0      .9999999  .0
.0      .0      .9999999
TESTSTAR 9 1 0. 6. 41.      28. 54. 30.
TESTSTAR 10 3 0. 54. 42.      60. 32. 19.
ENDCAS

```

```

0.0      360.0      0.0
.8485658  .4822678  -.2176093
-.4067026  .3314818  -.8513006

```

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